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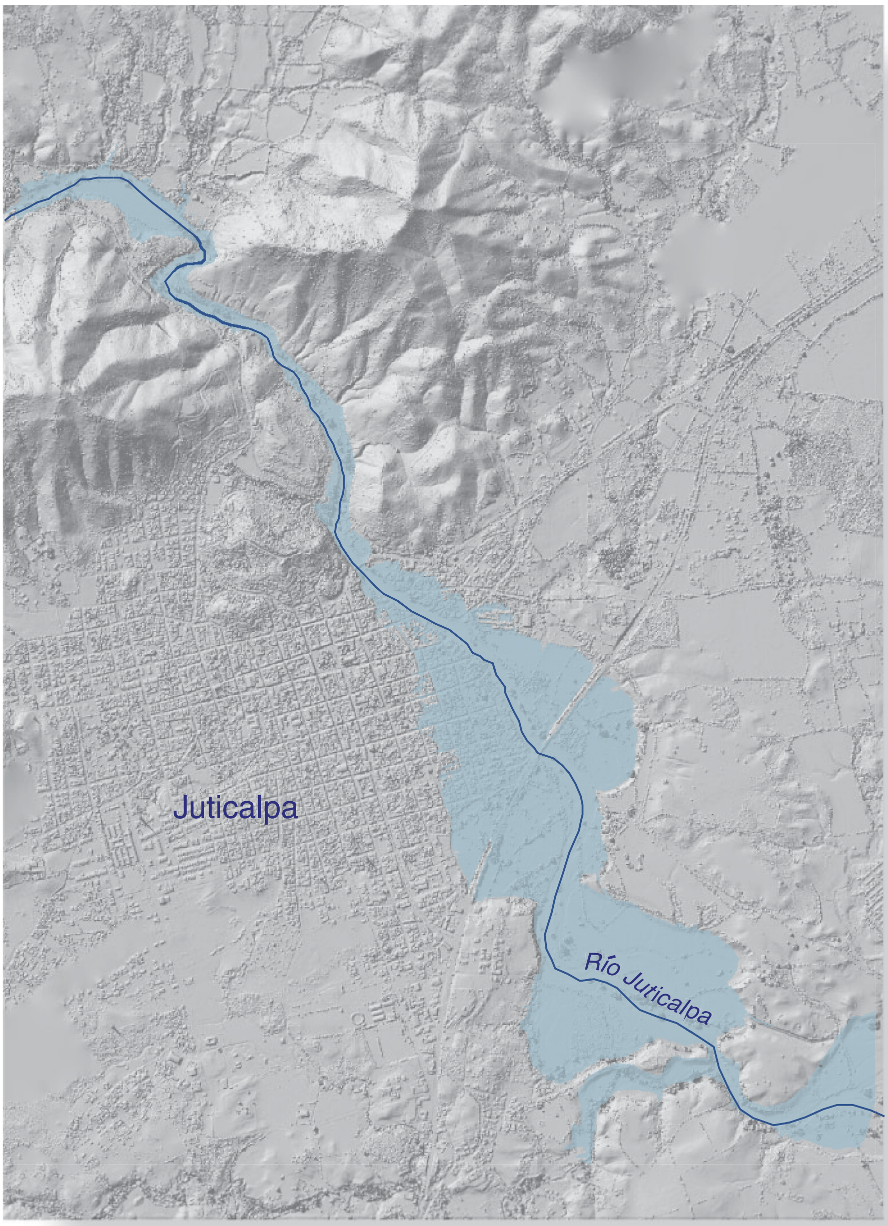
Fifty-Year Flood-Inundation Maps for Juticalpa, Honduras

U.S. Geological Survey Open-File Report 02-253



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Fifty-Year Flood-Inundation Maps for Juticalpa, Honduras

By David L. Kresch, Mark C. Mastin, and Theresa D. Olsen

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-253

Prepared in cooperation with the
U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

Tacoma, Washington
2002

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS

Multiply	By	To obtain
cubic meter per second (m^3/s)	35.31	cubic foot per second
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile

VERTICAL DATUM

Elevation: In this report "elevation" refers to the height, in meters, above the ellipsoid defined by the World Geodetic System of 1984 (WGS 84).

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ABSTRACT

After the devastating floods caused by Hurricane Mitch in 1998, maps of the areas and depths of 50-year-flood inundation at 15 municipalities in Honduras were prepared as a tool for agencies involved in reconstruction and planning. This report, which is one in a series of 15, presents maps of areas in the municipality of Juticalpa that would be inundated by a 50-year flood of Río Juticalpa. Geographic Information System (GIS) coverages of the flood inundation are available on a computer in the municipality of Juticalpa as part of the Municipal GIS project and on the Internet at the Flood Hazard Mapping Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html). These coverages allow users to view the flood inundation in much more detail than is possible using the maps in this report.

Water-surface elevations for a 50-year-flood on Río Juticalpa at Juticalpa were estimated using HEC-RAS, a one-dimensional, steady-flow, step-backwater computer program. The channel and floodplain cross sections used in HEC-RAS were developed from an airborne light-detection-and-ranging (LIDAR) topographic survey of the area. The estimated 50-year-flood discharge for Río Juticalpa at Juticalpa, 1,360 cubic meters per second, was computed as the drainage-area-adjusted weighted average of two independently estimated 50-year-flood discharges for the gaging station Río Juticalpa en El Torito, located about 2 kilometers upstream from Juticalpa. One discharge, 1,551 cubic meters per second, was estimated from a frequency analysis of the 33 years of peak-discharge record for the gage, and the other, 486 cubic meters per second, was estimated from a regression equation that relates the 50-year-flood discharge to drainage area and mean annual precipitation. The weighted-average of the two discharges at the gage is 1,310 cubic meters per second. The 50-year flood discharge for the study area reach of Río Juticalpa was estimated by multiplying the weighted discharge at the gage by the ratio of the drainage areas upstream from the two locations.

INTRODUCTION

In late October 1998, Hurricane Mitch struck the mainland of Honduras, triggering destructive landslides, flooding, and other associated disasters that overwhelmed the country’s resources and ability to quickly rebuild itself. The hurricane produced more than 450 millimeters (mm) of rain in 24 hours in parts of Honduras and caused significant flooding along most rivers in the country. A hurricane of this intensity is a rare event, and Hurricane Mitch is listed as the most deadly hurricane in the Western Hemisphere since the “Great Hurricane” of 1780. However, other destructive hurricanes have hit Honduras in recent history. For example, Hurricane Fifi hit Honduras in September 1974, causing 8,000 deaths (Rappaport and Fernandez-Partagas, 1997).

As part of a relief effort in Central America, the U.S. Agency for International Development (USAID), with help from the U.S. Geological Survey (USGS), developed a program to aid Central America in rebuilding itself. A top priority identified by USAID was the need for reliable flood-hazard maps of Honduras to help plan the rebuilding of housing and infrastructure. The Water Resources Division of the USGS in Washington State, in coordination with the International Water Resources Branch of the USGS, was given the task to develop flood-hazard maps for 15 municipalities in Honduras: Catacamas, Choloma, Choluteca, Comayagua, El Progreso, Juticalpa, La Ceiba, La Lima, Nacaome, Olanchito, Santa Rosa de Aguán, Siguatepeque, Sonaguera, Tegucigalpa, and Tocoa. This report presents and describes the determination of the area and depth of inundation in the municipality of Juticalpa that would be caused by a 50-year flood of Río Juticalpa.

The 50-year flood was used as the target flood in this study because discussions with the USAID and the Honduran Public Works and Transportation Ministry indicated that it was the most common design flood used by planners and engineers working in Honduras. The 50-year flood is one that has a 2-percent chance of being equaled or exceeded in any one year and on average would be equalled or exceeded once every 50 years.

Purpose, Scope, and Methods

This report provides (1) results and summary of the hydrologic analysis to estimate the 50-year-flood discharge used as input to the hydraulic model, (2) results of the hydraulic analysis to estimate the water-surface elevations of the 50-year-flood discharge at cross sections along the stream profile, and (3) 50-year-flood inundation maps for Río Juticalpa at Juticalpa showing area and depth of inundation.

The analytical methods used to estimate the 50-year-flood discharge, to calculate the water-surface elevations, and to create the flood-inundation maps are described in a companion report by Mastin (2002). Water-surface elevations along Río Juticalpa were calculated using HEC-RAS, a one-dimensional, steady-flow, step-backwater computer model, and maps of the area and depths of inundation were generated from the water-surface elevations and topographic information.

The channel and floodplain cross sections used in HEC-RAS were developed from an airborne light-detection-and-ranging (LIDAR) topographic survey of Juticalpa, and a ground survey at one bridge. Because of the high cost of obtaining high-resolution elevation data, the extent of mapping was limited to areas of high population density where flooding is expected to cause the worst damage. The findings in this report are based on the conditions of the river channel and floodplains on March 8, 2000, when the LIDAR data were collected, and January 18, 2001, when the bridge was surveyed.

Acknowledgments

We acknowledge USAID for funding this project; Jeff Phillips of the USGS for providing data and field support while we were in-country; Roger Bendeck, a Honduran interpreter, for being an indispensable guide, translator, and instrument man during our field trips; and Samuel Garcia, the mayor of Juticalpa, and Miguel Flores of the mayor's office, who gave us important local insights into the hydrology of and historical flooding along Río Juticalpa and allowed us access to the river during our field surveys.

DESCRIPTION OF STUDY AREA

Río Juticalpa flows from the northwest through the northeastern part of Juticalpa and then continues beyond Juticalpa to the southeast. The study area includes the river channel and floodplains of Río Juticalpa from approximately 2.5 kilometers (km) upstream from Juticalpa to 2 km downstream from Juticalpa (figure 1).

The river descends from the Montaña Casa de Tejas mountains in the north and enters the study area at a fairly steep gradient that gradually flattens downstream. The streambed material ranges from sand and gravel to cobbles and small to medium boulders, with exposures of bedrock in the upper portions of the reach. The main channel banks and floodplains are generally covered with dense vegetation.

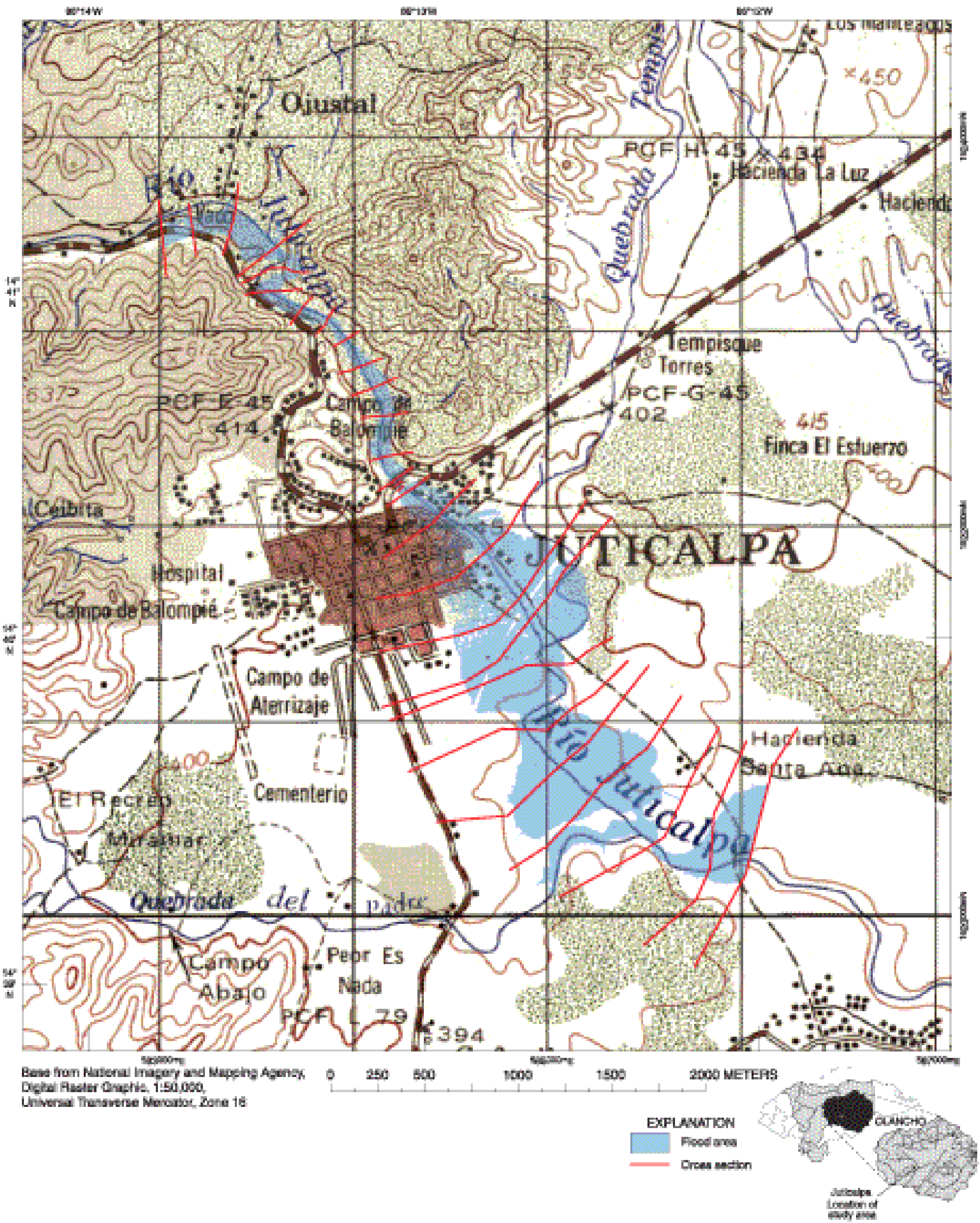

Figure 1. Location of study area and cross sections, and the area of inundation for the 50-year flood on Río Juticalpa at Juticalpa, Honduras.

FIFTY-YEAR FLOOD DISCHARGE

The estimated 50-year-flood discharge of Río Juticalpa at Juticalpa is the drainage-area adjusted weighted average of two independently estimated 50-year-flood discharges for the gaging station Río Juticalpa en El Torito; one from a frequency analysis of the annual peak-flow discharges at the gage and the other from a regression equation that relates the 50-year-flood discharge to drainage area and mean annual precipitation. The weights used in computing the average were inversely proportional to the variances of the individual variances. Weighted averages generally provide better estimates of true flood discharges than those determined from either a flood-frequency analysis or a regression equation alone.

The Río Juticalpa en El Torito stream-gaging station, which is operated by the Secretaría de Recursos Naturales y Ambiente (SERNA), the national natural resource agency in Honduras, is located about 2 km upstream from Juticalpa and has 33 years of annual peak flow record (table 1). The results of a frequency analysis of the annual peak discharges for the gaging station are shown in table 2 and in an exceedance probability plot (figure 2).

Table 1. Annual peak discharges at the stream-gaging station Río Juticalpa en El Torito, Honduras, for water years 1957–59, 1965–88, 1991, 1993–1997

[**Water year**: (May 1 through April 30) is identified by the calendar year in which it begins. For example, the 1957 water year begins on May 1, 1957, and ends on April 30, 1958; **Abbreviations**: m^3/s, cubic meters per second]

Water year	Discharge (m^3/s)	Water year	Discharge (m^3/s)
1957	46.6	1979	245
1958	106	1980	88.8
1959	21.4	1981	106
1965	91.7	1982	105
1966	642	1983	54.3
1967	764	1984	89.9
1968	1,060	1985	60.5
1969	1,920	1986	126
1970	351	1987	88.0
1971	152	1988	182
1972	598	1991	252
1973	83.9	1993	135
1974	480	1994	82.3
1975	149	1995	193
1976	50.8	1996	144
1977	289	1997	435
1978	72.8		

Table 2. Results of frequency analysis of annual peak flow for the stream-gaging station Río Juticalpa en El Torito, Honduras, for water years 1957–59, 1965–88, 1991, 1993–97

[**Abbreviations**: m^3/s, cubic meters per second]

Annual exceedance probability (percent)	Average recurrence interval (years)	Peak flow		
		Estimated value (m^3/s)	95-percent confidence limits	
			Lower (m^3/s)	Upper (m^3/s)
99.5	1.005	17.9	9.3	28.4
99	1.01	21.3	11.5	33.0
95	1.05	35.5	21.4	51.4
90	1.1	47.6	30.4	66.8
80	1.2	69.3	47.3	94.3
50	2	153	114	204
20	5	368	272	537
10	10	606	428	964
4	25	1,062	701	1,897
2	50	1,551	973	3,015
1	100	2,204	1,316	4,649
0.5	200	3,070	1,744	7,003
0.2	500	4,642	2,476	11,700

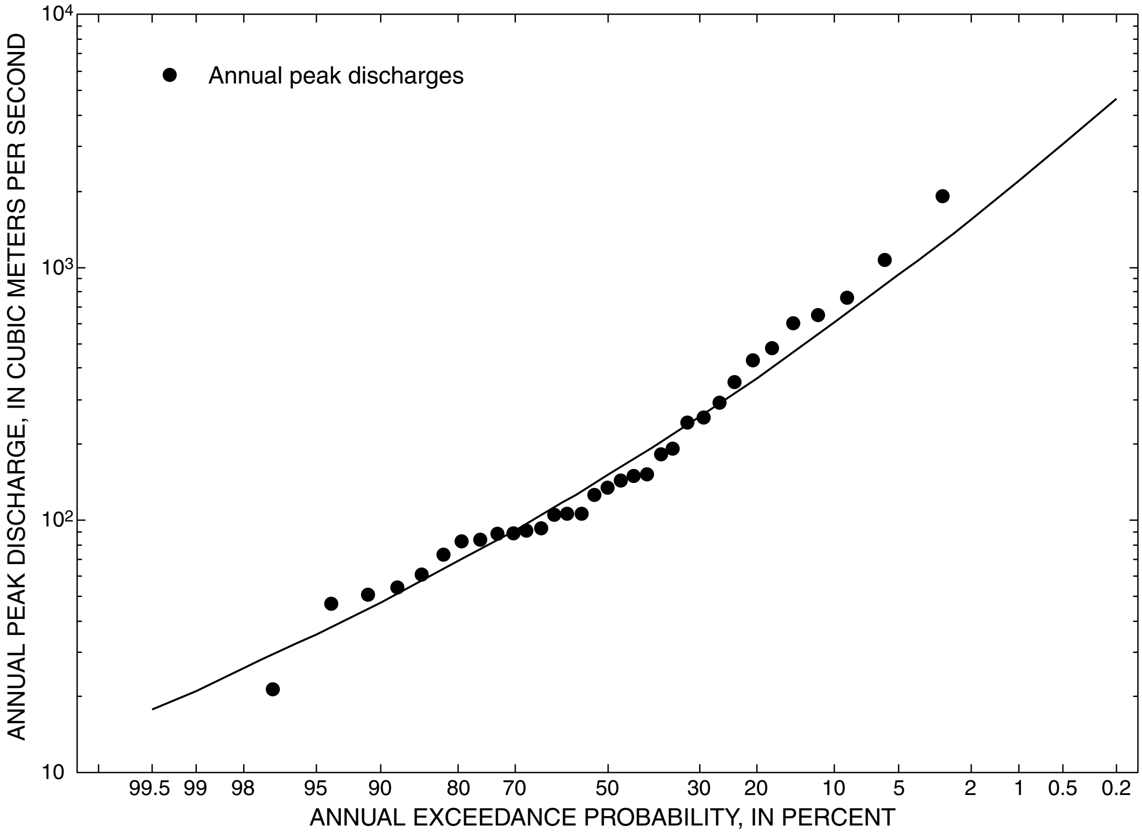

Figure 2. Exceedance probability of annual peak discharge for stream-gaging station Río Juticalpa en El Torito, Honduras.

As shown in table 2, the 2-percent exceedance probability (50-year frequency) peak discharge calculated from the gaging station record is 1,551 cubic meters per second (m^3/s).

A regression equation (equation 1) that relates the 50-year peak flow with drainage area and mean annual precipitation was developed using data from 34 streamflow stations throughout Honduras with more than 10 years of annual peak flow record (Mastin, 2002).

$$Q_{50} = 0.0788(DA)^{0.5664}(P)^{0.7693}\,, \qquad (1)$$

where

Q_{50} is the 50-year-flood discharge, in cubic meters per second (m^3/s),

DA is drainage area, in square kilometers (km^2), and

P is mean annual precipitation over the basin, in mm.

The standard error of estimate of equation 1, which is a measure of the scatter of data about the regression equation, is 0.260 log unit, or 65.6 percent. The standard error of prediction, which is a measure of how well the regression equation predicts the 50-year-flood discharge and includes the scatter of the data about the equation plus the error in the regression equation, equals 0.278 log unit, or 71.3 percent

The drainage area upstream of the El Torito gaging station (414 km^2) and upstream of Juticalpa (431 km^2) were established using a geographic information system (GIS) program to analyze a digital elevation model (DEM) with a 93-meter cell resolution from the National Imagery and Mapping Agency (David Stewart, USGS, written commun., 1999). The mean annual precipitation over the gaging-station basin was determined to be 1,000 mm using a GIS program to analyze a digitized map of mean annual precipitation at a scale of 1:2,500,000 (Morales-Canales, 1997-1998, p. 15). The 50-year-flood discharge estimated from regression equation 1 for the gaging-station basin was 486 m^3/s.

The weighted average of the two estimated 50-year-flood discharges at the El Torito gaging station (1,551 m^3/s and 486 m^3/s) is 1,310 m^3/s. The 50-year-flood discharge at Juticalpa (1,360 m^3/s) was estimated by multiplying the weighted-average discharge at the gage by the ratio of the drainage areas upstream from the two locations.

WATER-SURFACE PROFILE OF THE 50-YEAR FLOOD

Once a 50-year flood discharge has been estimated, a profile of water-surface elevations along the course of the river can be estimated for the 50-year flood with a step-backwater model, and later used to generate the flood-inundation maps. The U.S. Army Corps of Engineers HEC-RAS modeling system was used for step-backwater modeling. HEC-RAS is a one-dimensional, steady-flow model for computing water-surface profiles in open channels, through bridge openings, and over roads. The basic required inputs to the model are stream discharge, cross sections (geometry) of the river channels and floodplains perpendicular to the direction of flow, bridge geometry, Manning’s roughness coefficients (*n* values) for each cross section, and boundary conditions (U.S. Army Corps of Engineers, 1998).

Cross-section geometry was obtained from a high-resolution DEM created from an airborne LIDAR survey. The LIDAR survey was conducted by personnel from the University of Texas. A fixed-wing aircraft with the LIDAR instrumentation and a precise global positioning system (GPS) flew over the study area on March 8, 2000. The relative accuracy of the LIDAR data was determined by comparing LIDAR elevations with GPS ground-surveyed elevations at 417 points in the Juticalpa study area. The mean difference between the two sets of elevations is -0.169 meter, and the standard deviation of the differences is 0.088 meter. The LIDAR data were filtered to remove vegetation while retaining the buildings to create a “bare earth” elevation representation of the floodplain.

The LIDAR data were processed into a GIS (Arc/Info™) GRID raster coverage of elevations at a 1.5-meter cell resolution. The coverage was then processed into a triangular irregular network (TIN) GIS coverage. Cross sections of elevation data oriented across the floodplain perpendicular to the expected flow direction of the 50-year-flood discharge (figure 1) were obtained from the TIN using HEC-GeoRAS, a pre- and post-processing GIS program designed for HEC-RAS (U.S. Army Corps of Engineers, 2000). The underwater portions of the cross sections cannot be seen by the LIDAR system. However, because the LIDAR surveys were conducted during a period of extremely low flows, the underwater portions were assumed to be insignificant in comparison with the cross-sectional areas of flow during a 50-year flood; therefore, they were not included in the model.

A reconnaissance visit to the study area was made on October 19, 1999, to determine whether any bridges over Río Juticalpa needed to be surveyed for inclusion in the HEC-RAS model. Two bridges were found: one highway bridge near the north end of town at cross section 3.360 and another near the south end of town at cross section 2.380. The geometry of the bridge at cross section 3.360 was surveyed on January 18, 2001. The highway bridge at cross section 2.380, which was severely damaged by floodwaters from Hurricane Mitch, was being dismantled when visited on January 18, 2001. Therefore, it was not included in the HEC-RAS model. If the dismantled bridge is replaced with a new bridge, water-surface elevations at and upstream of the new bridge may be higher than those estimated in this study.

Most hydraulic calculations of flow in channels and overbank areas require an estimate of flow resistance, which is generally expressed as Manning's roughness coefficient, *n*. The effect that roughness coefficients have on water-surface profiles is that as the *n* value is increased, the resistance to flow increases also, which results in higher water-surface elevations. Roughness coefficients (Manning's *n*) for Río Juticalpa were estimated from digital photographs taken during the field visits of the study area on October 19, 1999, and January 18, 2001, and from computer displays of shaded-relief images of the LIDAR-derived DEM before the vegetation removal filter was applied. An *n* value of 0.040 was estimated for the main channel of Río Juticalpa, and the estimated *n* values for the floodplain areas ranged from 0.045 to 0.065.

Step-backwater computations require a water-surface elevation as a boundary condition at either the downstream end of the stream reach for flows in the subcritical flow regime or at the upstream end of the reach for flows in the supercritical flow regime. Initial HEC-RAS simulations indicated that the flow in Río Juticalpa would be in the subcritical flow regime. Therefore, the boundary condition used was a water-surface elevation at cross section 0.084, the farthest downstream cross-section in the Río Juticalpa step-backwater model. This elevation, 373.82 meters, was estimated by a slope-conveyance computation assuming an energy gradient of 0.00208, which was estimated to be equal to the slope of the main channel bed. The computed water-surface elevations at the first few cross sections upstream may differ from the true elevations if the estimated boundary condition elevation is incorrect. However, if the error in the estimated boundary condition is not large, the computed profile asymptotically approaches the true profile within a few cross sections.

The step-backwater model provided estimates of water-surface elevations at all cross sections for the 50-year-flood discharge (table 3 and figure 3).

Table 3. Estimated water-surface elevations for the 50-year-flood on Río Juticalpa at Juticalpa, Honduras

[Peak flow for the 50-year flood is 1,360 cubic meters per second. **Cross-section stationing**: distance upstream from an arbitrary point near the model boundary; **Minimum channel elevation**, **Water-surface elevation**: elevations are referenced to the World Geodetic System Datum of 1984; **Abbreviations**: km, kilometers; m, meters; m/s, meters per second]

Cross-section stationing (km)	Minimum channel elevation (m)	Average velocity of flow (m/s)	Water-surface elevation (m)
5.806	392.61	6.20	398.61
5.633	392.27	3.83	398.41
5.396	390.86	3.53	397.57
5.116	389.76	3.73	396.43
4.947	389.36	4.02	395.85
4.742	387.62	3.83	395.44
4.538	386.42	3.40	395.13
4.385	385.53	6.60	392.47
4.238	383.58	5.69	390.33
4.061	383.52	4.69	389.64
3.928	382.39	3.38	389.65
3.762	381.93	4.42	388.39
3.532	380.77	3.28	388.31
3.395	381.15	4.85	387.24
3.370	380.43	4.00	387.37
3.360 (bridge)			
3.350	380.43	5.09	386.42
3.305	380.81	3.90	386.67
3.089	379.88	4.21	385.09
2.763	379.08	2.61	384.07
2.436	378.09	3.23	382.47
2.315	377.70	3.30	381.68
2.018	376.38	2.39	380.74
1.655	375.51	2.13	380.00
1.334	374.42	1.34	379.85
1.102	373.06	1.08	379.77
0.650	371.64	6.48	377.09
0.305	370.67	3.00	374.51
0.084	370.21	1.45	373.82

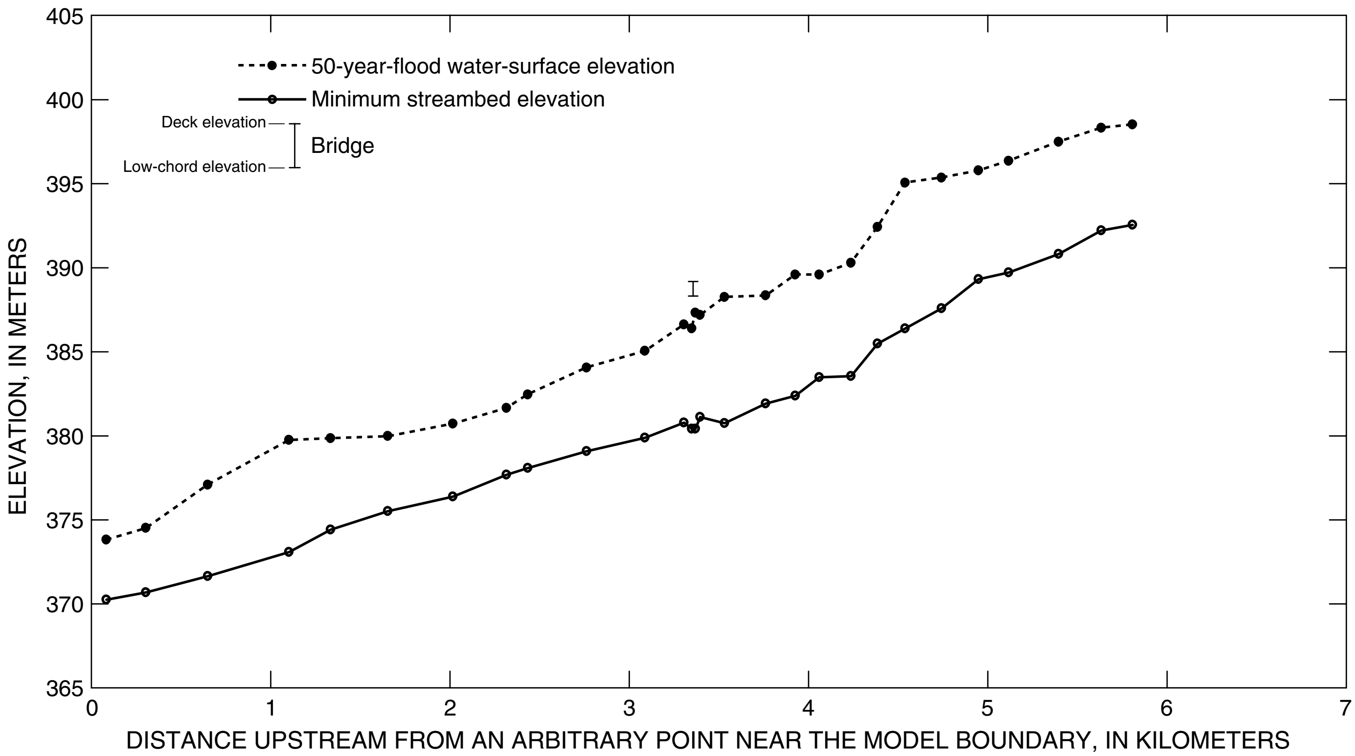

Figure 3. Water-surface profile, estimated using the step-backwater model HEC-RAS, for the 50-year flood on Río Juticalpa at Juticalpa, Honduras.

FIFTY-YEAR FLOOD-INUNDATION MAPS

The results from the step-backwater hydraulic model were processed by the computer program HEC-GeoRAS to create GIS coverages of the area and depth of inundation for the study area. The GIS coverage of area of inundation was created by intersecting the computed water-surface elevations with the topographic TIN that was produced from the LIDAR data. This coverage was then overlain on an existing 1:50,000 topographic digital raster graphics map (figure 1) produced by the U.S. National Imagery and Mapping Agency (Gary Fairgrieve, USGS, written commun., 1999). Depth of inundation at Juticalpa for a 50-year-flood on Río Juticalpa (figure 4) was computed by subtracting the topographic TIN from a computed water-surface elevation TIN to produce a grid with a cell size of 2 meters.

The flood-hazard maps are intended to provide a basic tool for planning or for engineering projects in or near the Río Juticalpa floodplain. This tool can reasonably separate high-hazard from low-hazard areas in the floodplain to minimize future flood losses. However, significant introduced or natural changes in main-channel or floodplain geometry or location can affect the area and depth of inundation. Also, encroachment into the floodplain with structures or fill will reduce flood-carrying capacity and thereby increase the potential height of floodwaters, and may also increase the area of inundation.

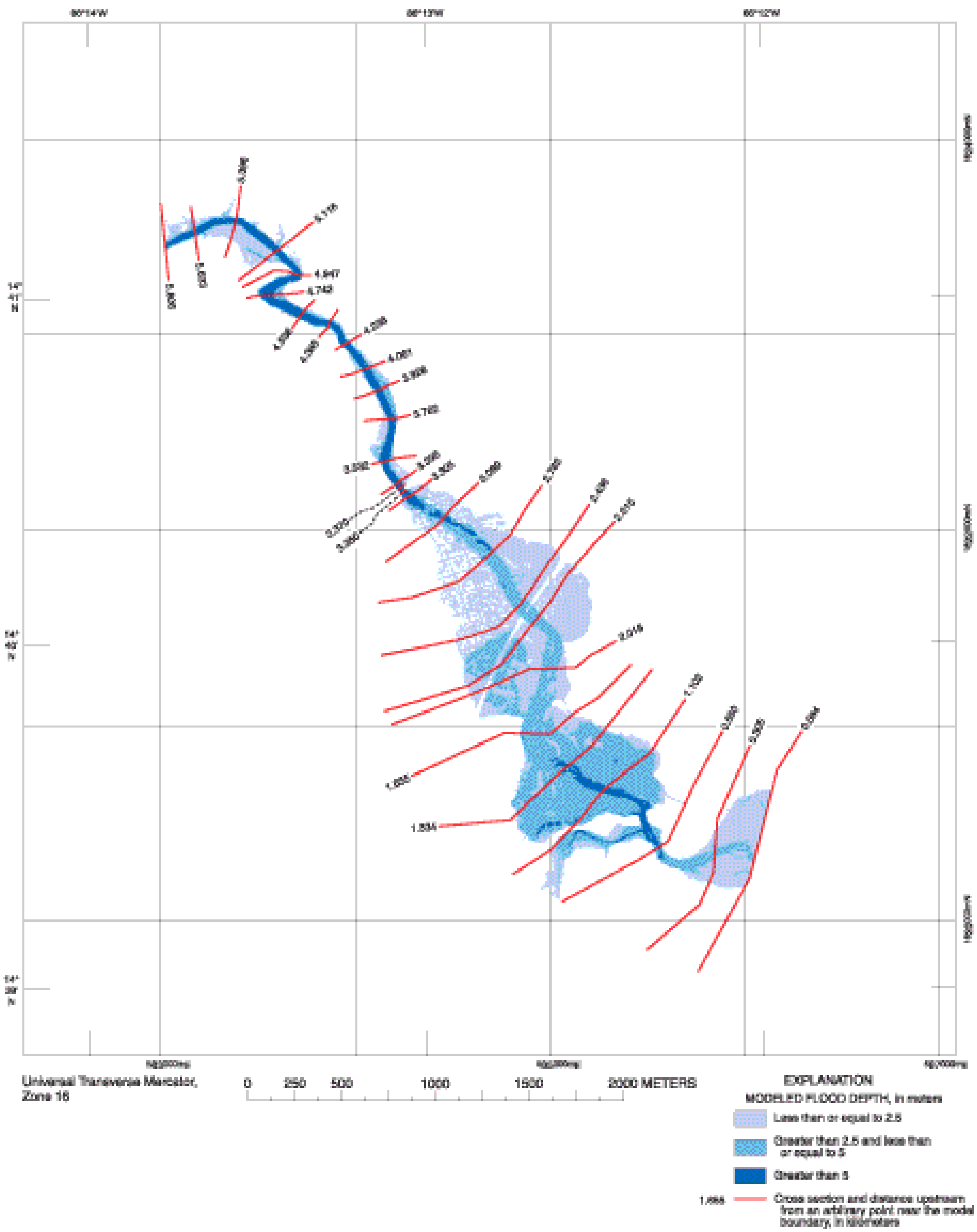

Figure 4. Depth of inundation of the 50-year flood and location of cross sections on Río Juticalpa at Juticalpa, Honduras.

DATA AVAILABILITY

GIS coverages of flood inundation and flood depths shown on the maps in figures 1 and 4 are available in the Municipal GIS project, a concurrent USAID-sponsored USGS project that will integrate maps, orthorectified aerial photography, and other available natural resource data for a particular municipality into a common geographic database. The GIS project, which is located on a computer in the Juticalpa municipality office, allows users to view the GIS coverages in much more detail than shown on figures 1 and 4. The GIS project will also allow users to overlay other GIS coverages over the inundation and flood-depth boundaries to further facilitate planning and engineering. Additional information about the Municipal GIS project is available on the Internet at the GIS Products Web page (http://mitchnts1.cr.usgs.gov/projects/gis.html), a part of the USGS Hurricane Mitch Program Web site.

The GIS coverages and the HEC-RAS model files for this study are available on the Internet at the Flood Hazard Mapping Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html), which is also a part of the USGS Hurricane Mitch Program Web site.

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